Nanoparticle/AMC Contamination Control and Metrology for the EUVL Systems

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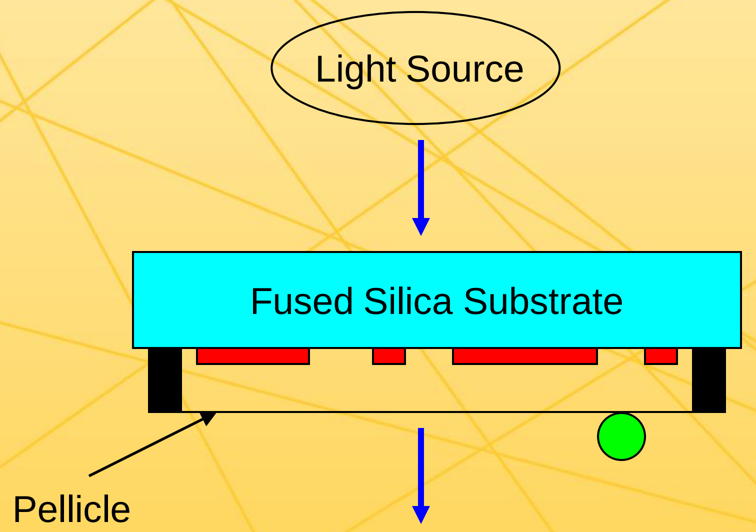
University of Minnesota

Outline

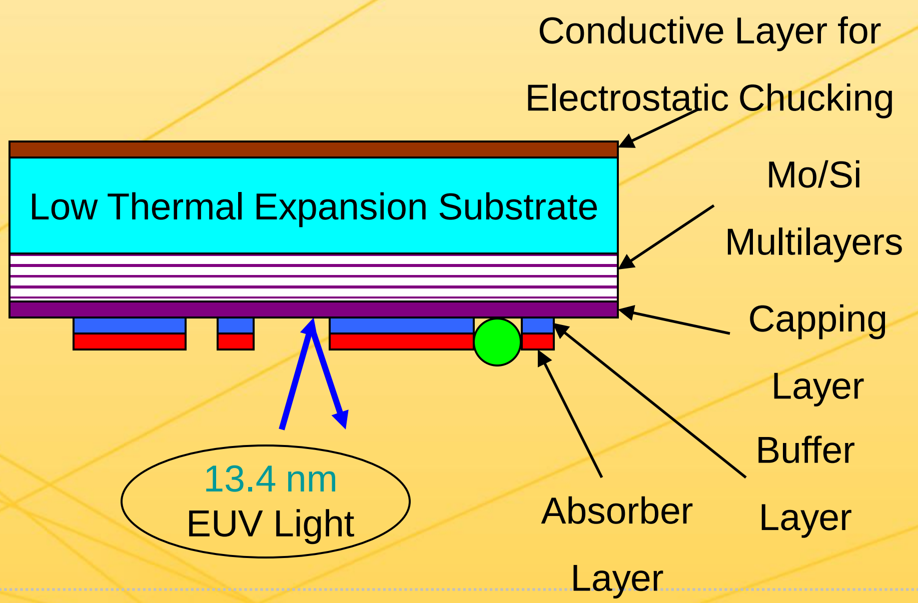
- Background and Motivation
- Protection Schemes for EUVL Masks
  - Carriers at Atmospheric Pressure
  - Scanners at below 100 mTorr
- Nanoparticle Metrology and AMC Issues
  - Standardization of Nanoparticles
  - Mask Deposition and AMC Issues

Background and Motivation

Conventional Optical Lithography



Extreme Ultraviolet Lithography

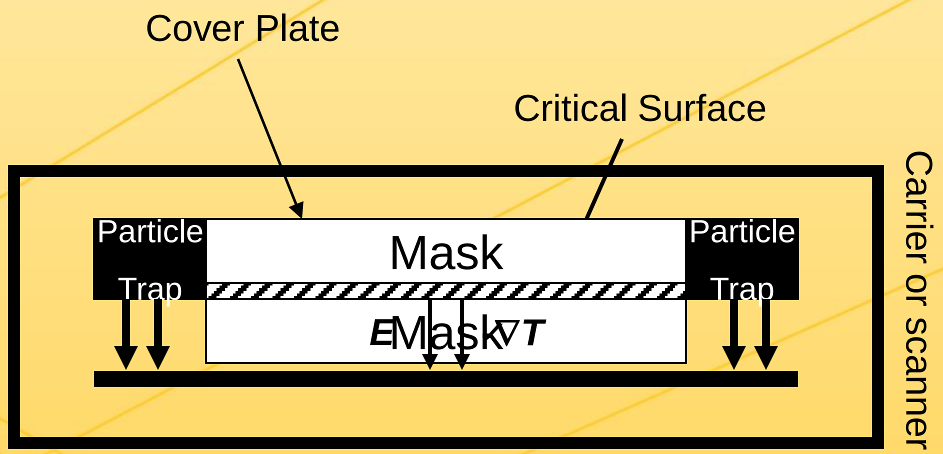


- Pellicles are unavailable for protecting the EUVL masks due to high absorption of EUV beam in most solid materials
- EUVL masks need to be protected against all particles > about 20 nm

Protection Schemes

The Intel project started in 2004. Particle contamination of EUVL photomasks was unknown. It was feared that thousands of particles might deposit on the mask during each operation. We need to investigate a broad range of protection schemes.

- Mask inside a carrier or scanner
- Cover plate to reduce risk volume
- Critical surface upside down to avoid gravitational settling (Cover plate underneath mask during shipping, storage, and pump down)



- Electric field to make use of electrophoresis
- Thermal gradient to make use of thermophoresis
- Particle trap surrounding mask to avoid particle penetration from the side

Asbach et al., *Journal of Nanoparticle Research 8:705-708 (2006)*

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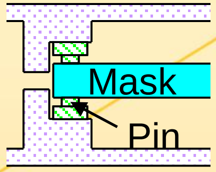
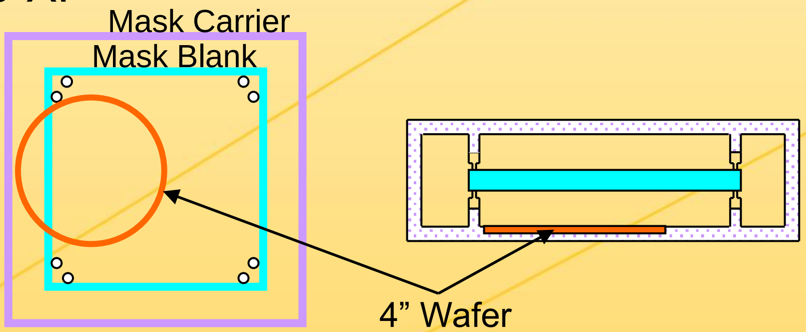
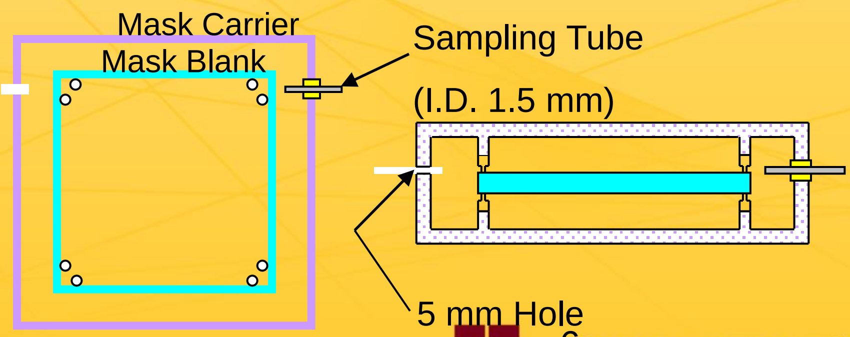
Particle Detection Methods



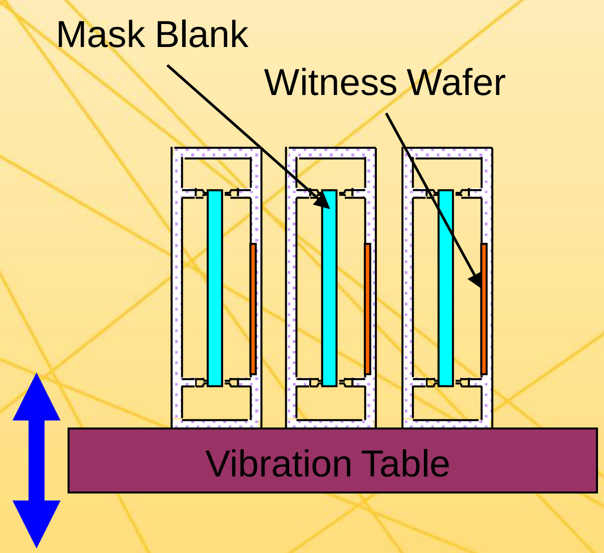
- **Surface particle detection**
  - **Mask Scan**: Lasertec M1350
  - **Wafer Scan**: PMS SAS 3600 XP

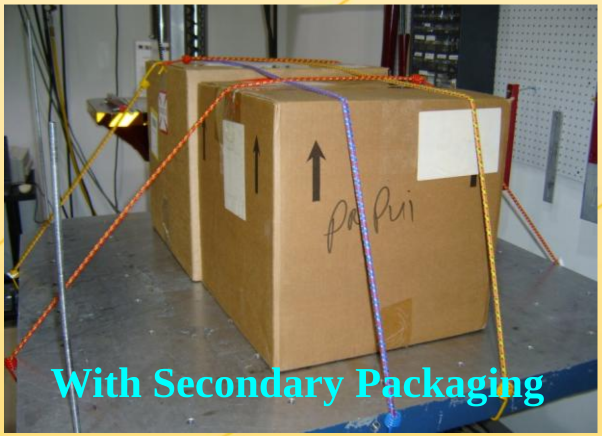


- **Airborne particle detection**
  - Laser particle counter (**HS-LAS**) for size distribution
  - Aerosol Time-of Flight Mass Spectrometer (**ATOFMS**) for particle chemical composition



Effect of Secondary Packaging

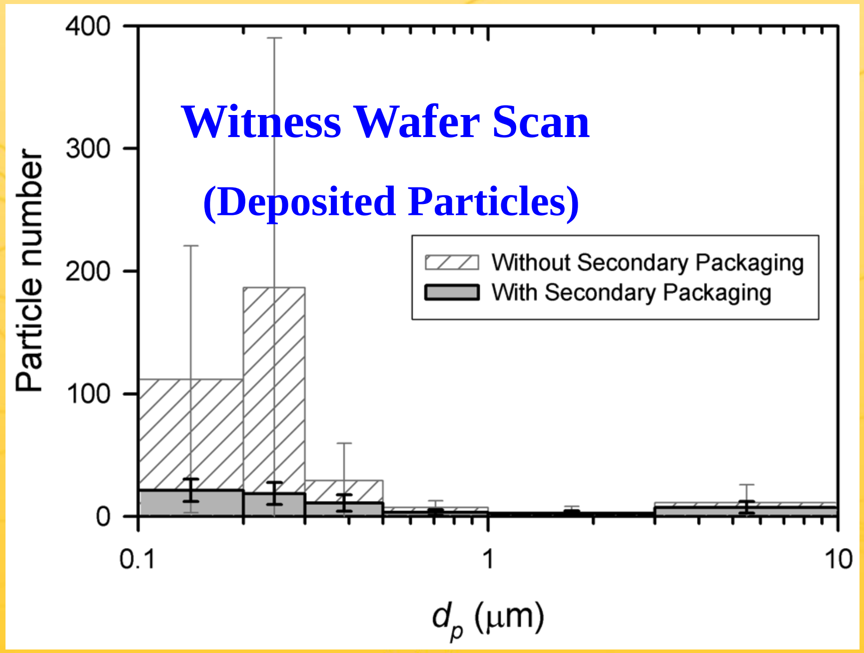




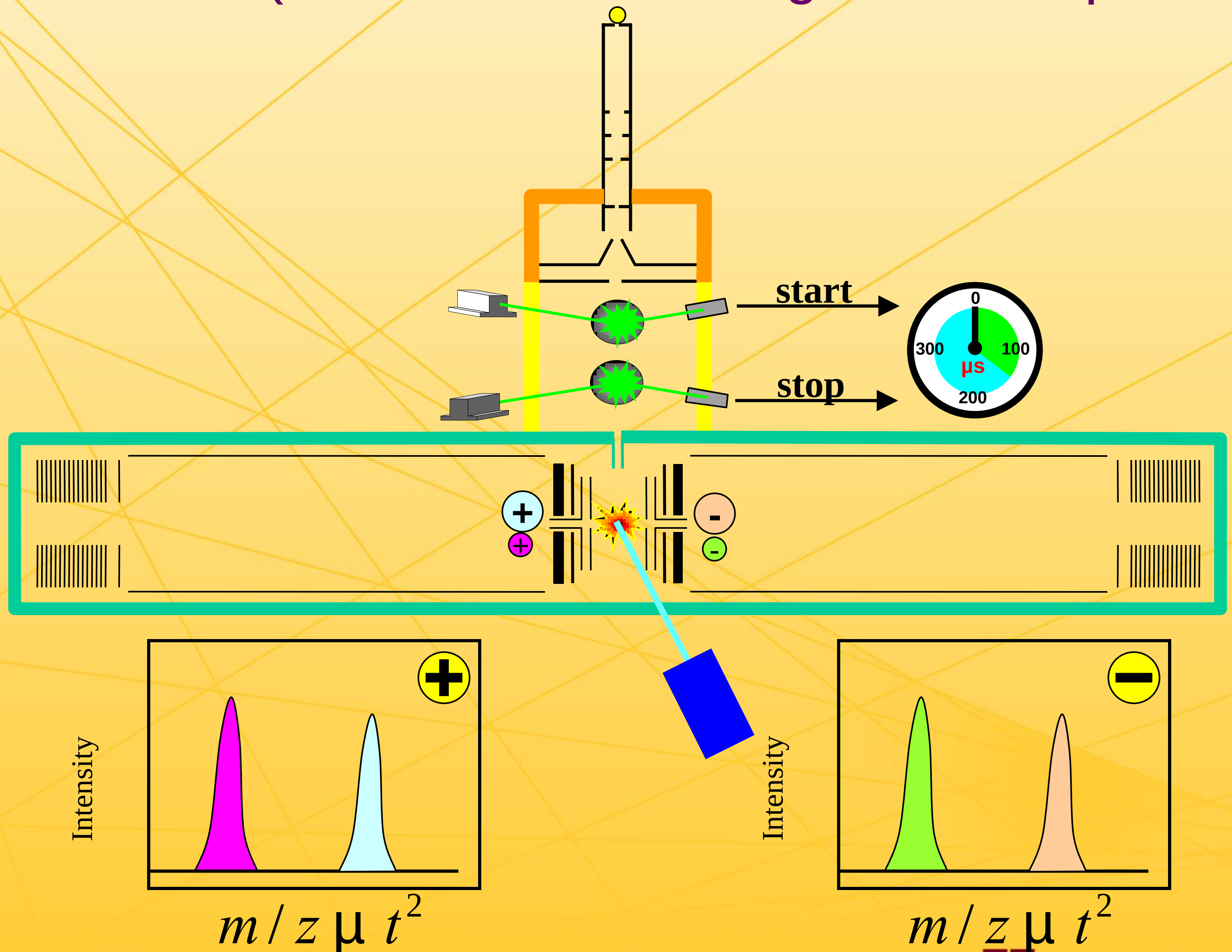
Controlled Vibration

- ISTA Procedure 1G at 1.15 G_{rms}
- Vertical position
- Particle detection on 4" wafers

• Secondary packaging is helpful in reducing particle generation



ATOFMS (Aerosol Time-of-Flight Mass Spectrometers)



Particle Inlet

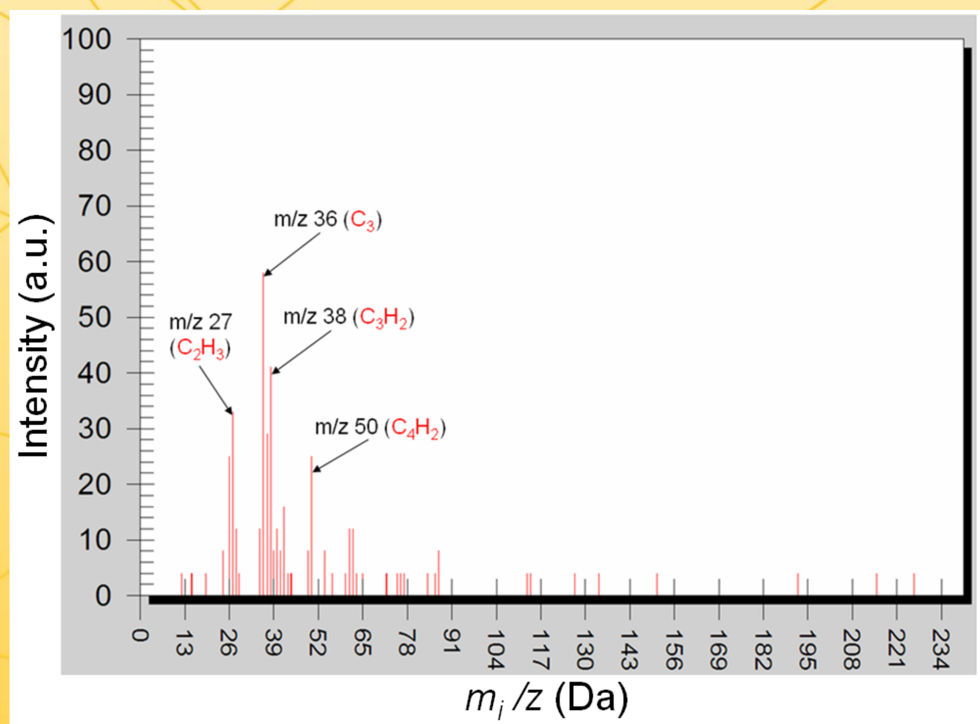
Particle Sizing

Particle Composition

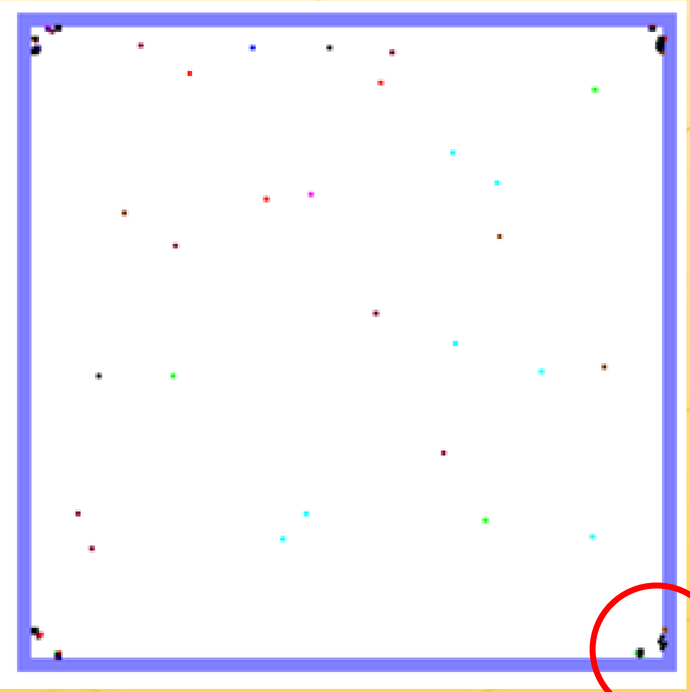
D. Gross, Carleton College, Based on TSI, Inc. schematic.

Particle Source Identification

ATOFMS



Mask Scan



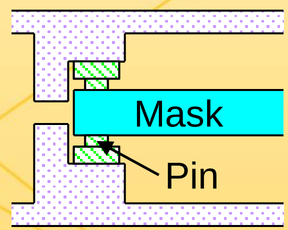
- Complex organic compound or mixture -- possibly polymer
- Contact points between the mask surface and pins

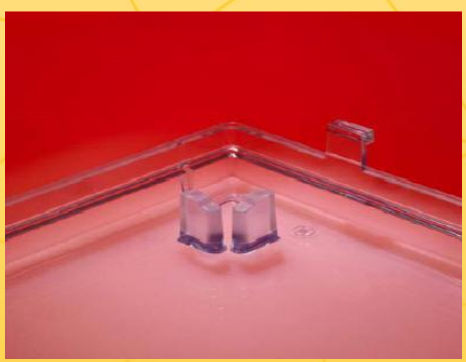
Particles come mostly from contact points between mask surface and pins

Yook et al., *IEEE Trans. Semi. Manu.* **20(2):** 176-186 (2007).

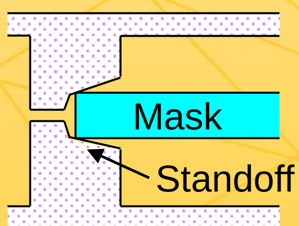
Validation of Pozzetta Carrier Design on Particle Generation during Real Shipping

PZT600-51125

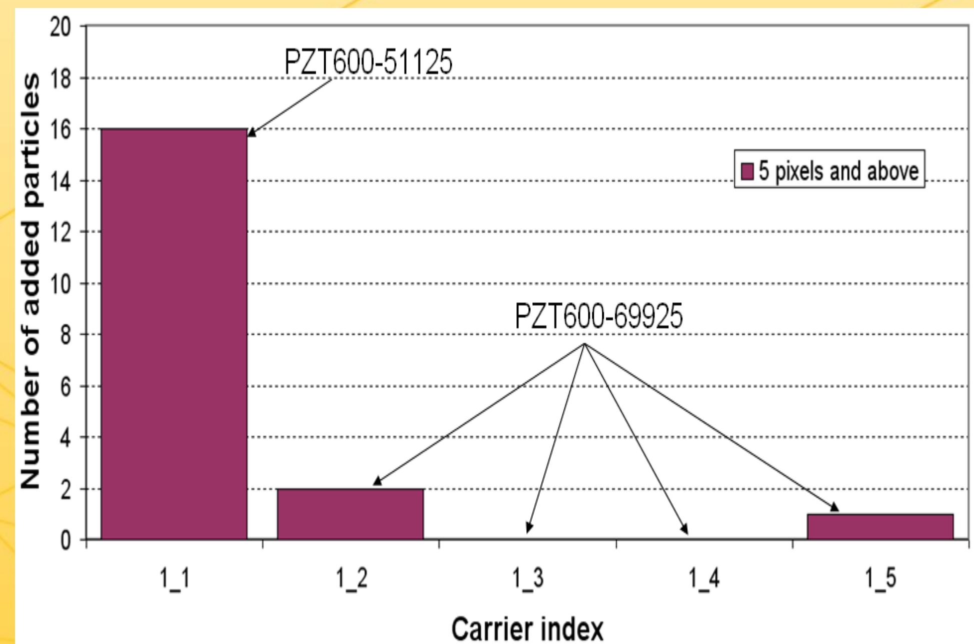




PZT600-69925



Mask Scan



- The pin-support generates considerable particles during shipping.
- The standoff-support generates almost no particles.

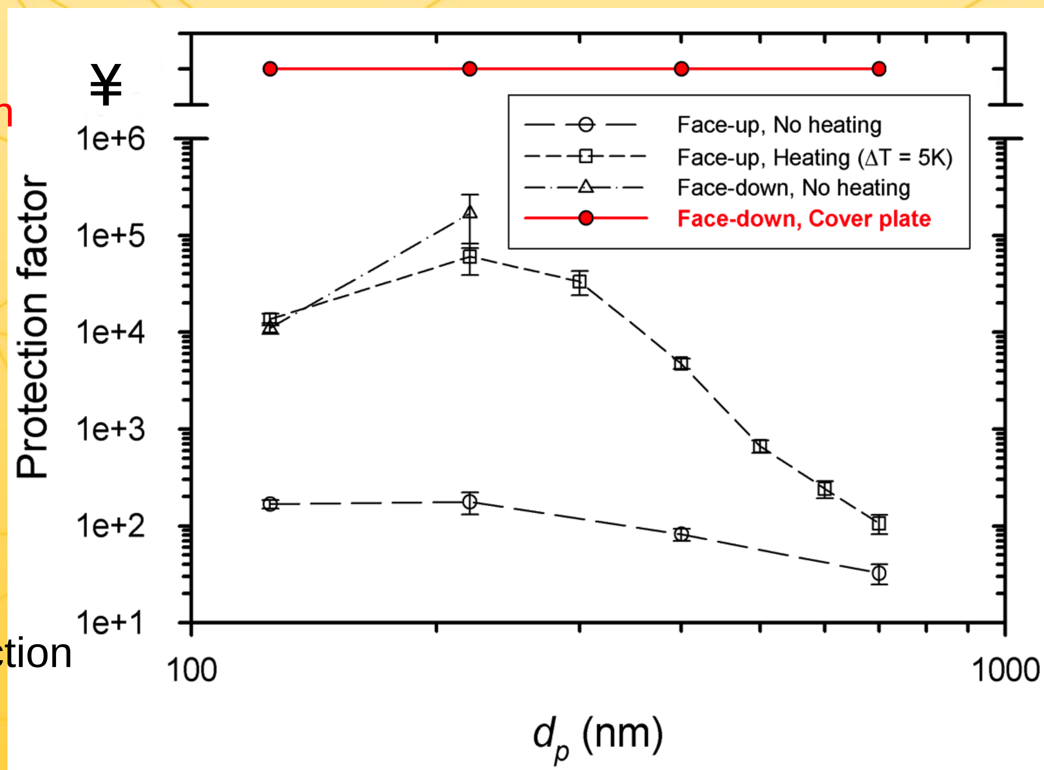
Study of Various Protection Schemes inside a Carrier

$$PF = \frac{\text{Number of injected particles into the chamber}}{\text{Number of deposited particles on the wafer}}$$

Absolute Protection

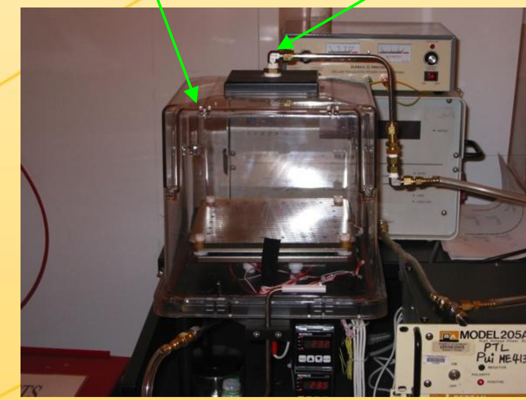
PF

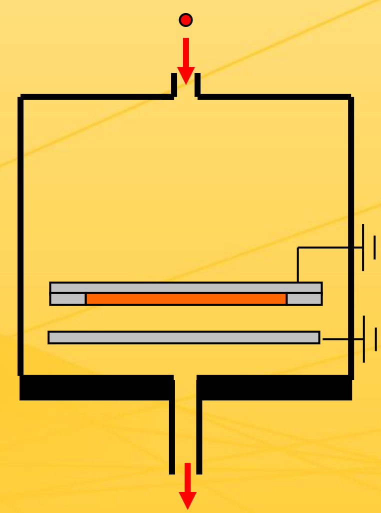
No Protection



Chamber Cover

Top Injection

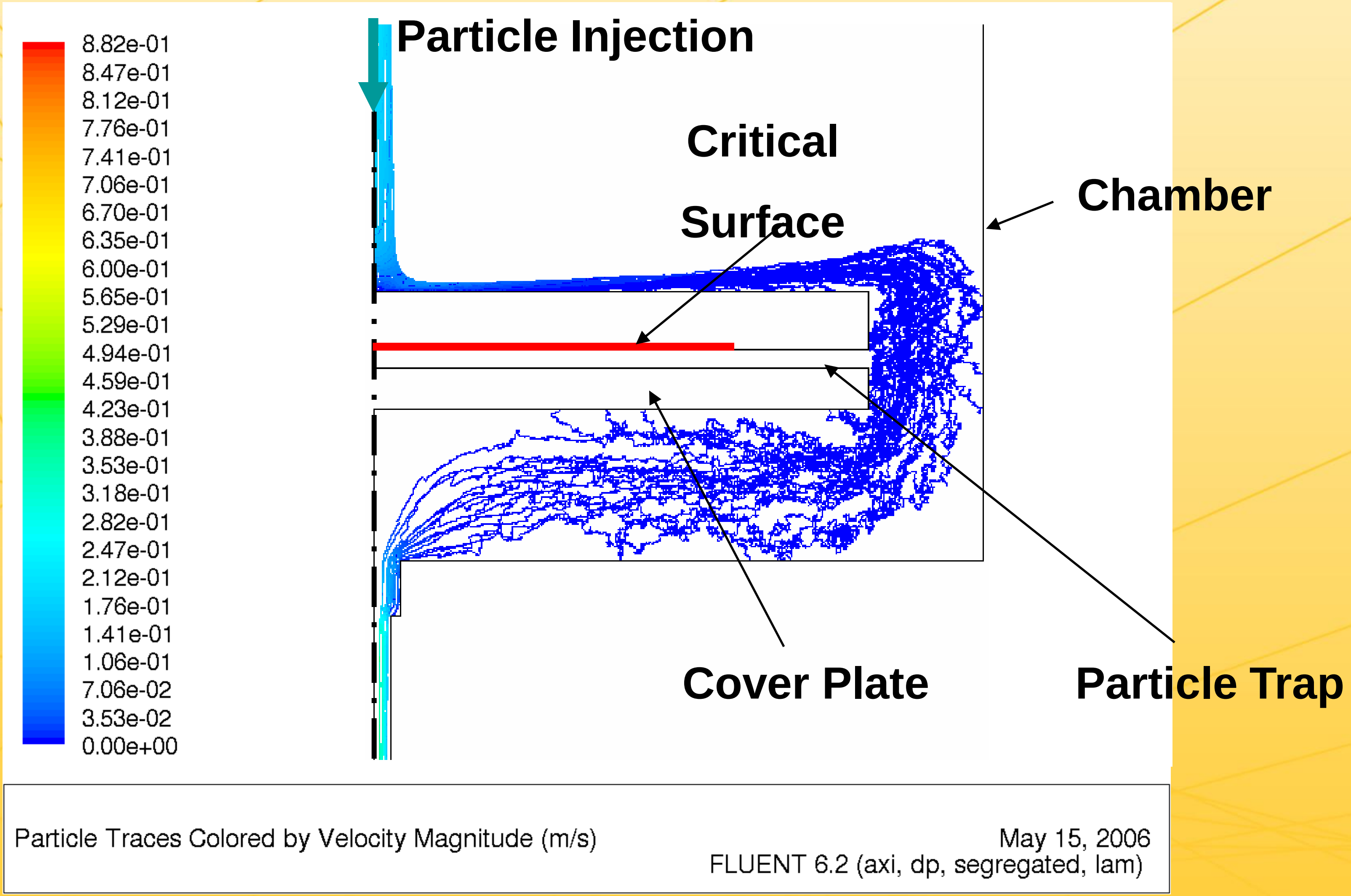




• No particle deposition with face-down mounting and a cover plate

Yook et al., J. Aerosol Sci. 38:211-227 (2007).

Effect of Cover Plate Protection (d_p = 10 nm)



- No particle deposition on the critical surface down to d_p = 10 nm

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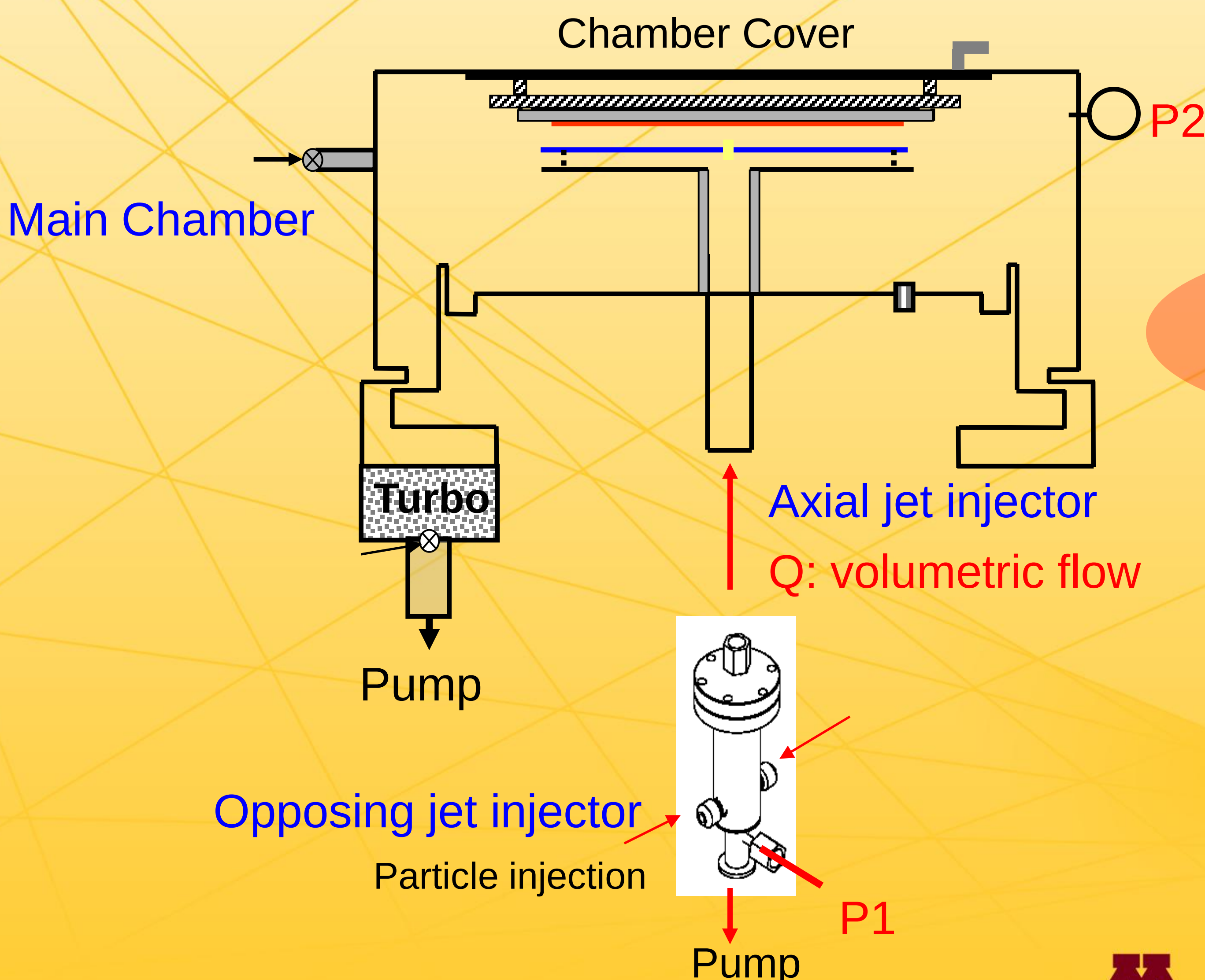
Experimental Setup

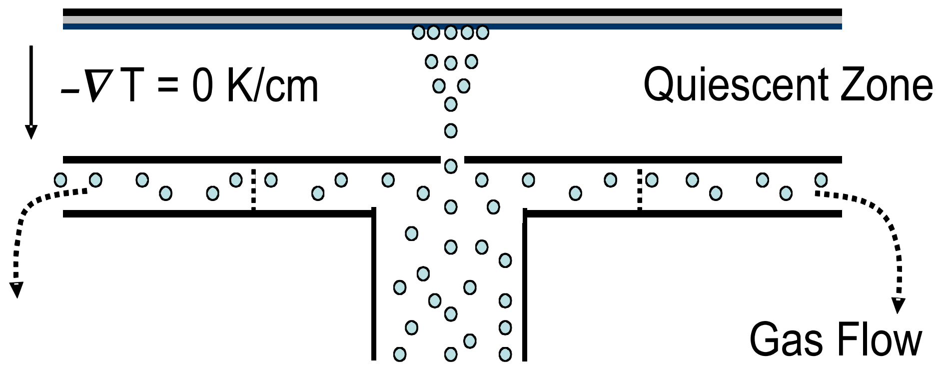


$$v_P = \frac{Q}{A} \times \frac{P_1}{P_2}$$

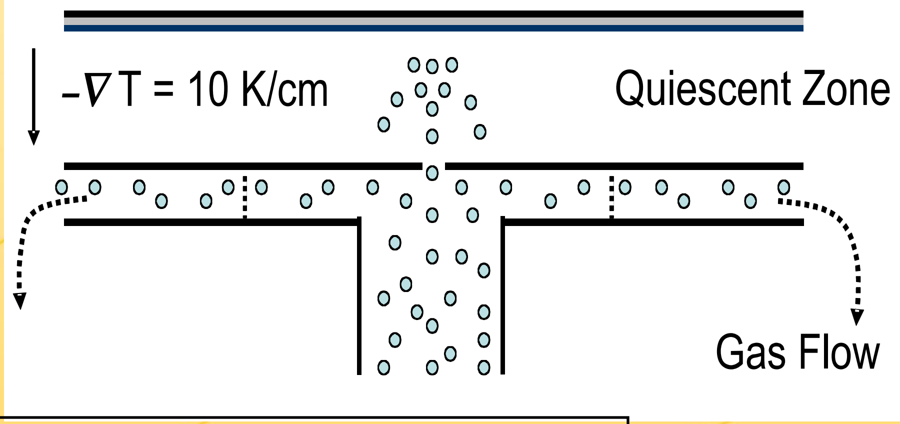
Kim, J.H. et al., *J. Vacuum Sci. Technol. A24(2):229-234 (2005)*

Thermophoresis Test Set Up

No Gradient



With Gradient

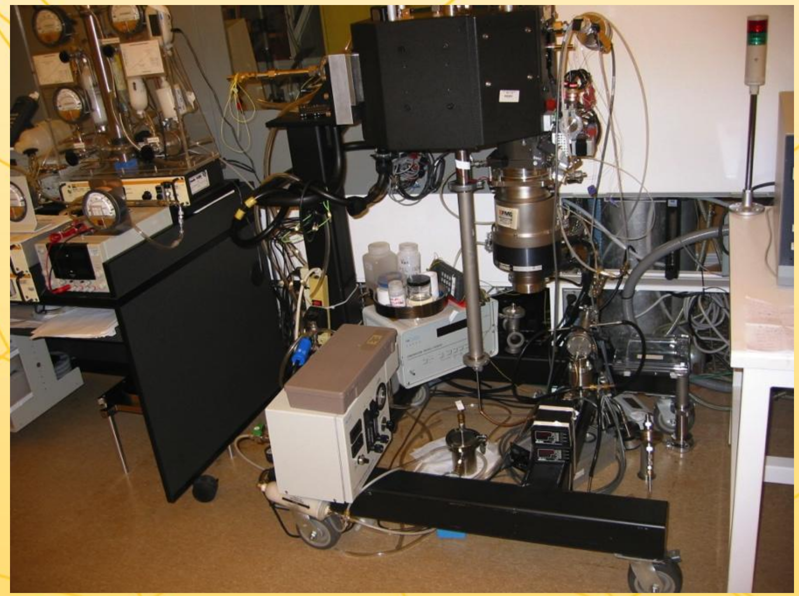


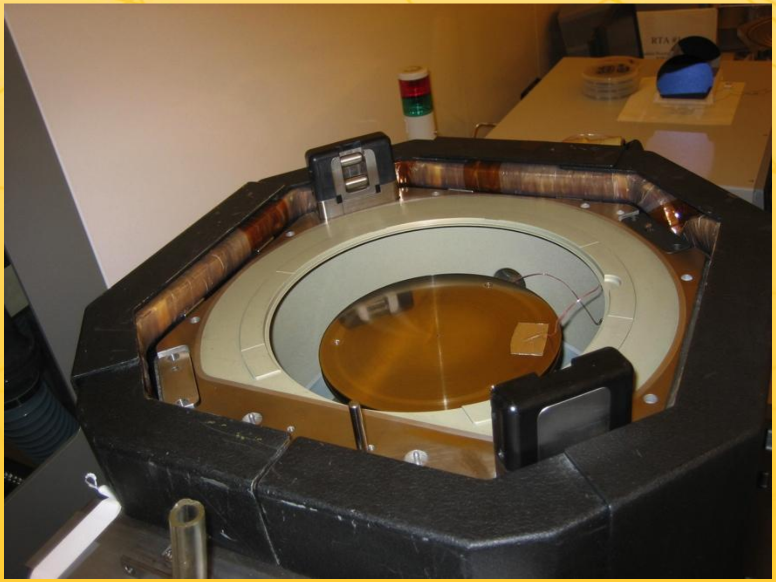
<u>Experimental cases:</u>

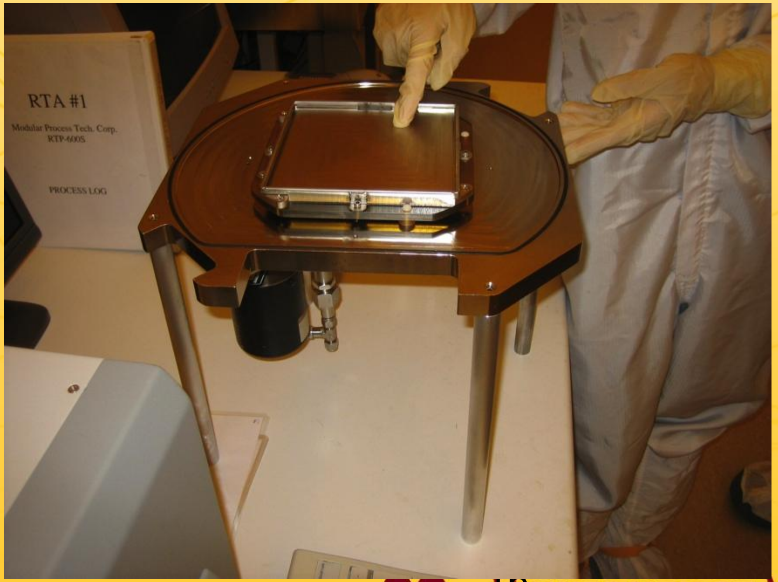
P:	100 mTorr, 50 mTorr
∇T:	0 K/cm, -10 K/cm
d_p:	125 nm, 220 nm (on wafers)
	70 nm, 100 nm (on masks)
v_i:	below, at, or above critical speed
Gap:	1, 2 or 3 cm

Kim, J.H. et al., *J. Vacuum Sci. Technol. B24(3):1178-1184 (2005)*

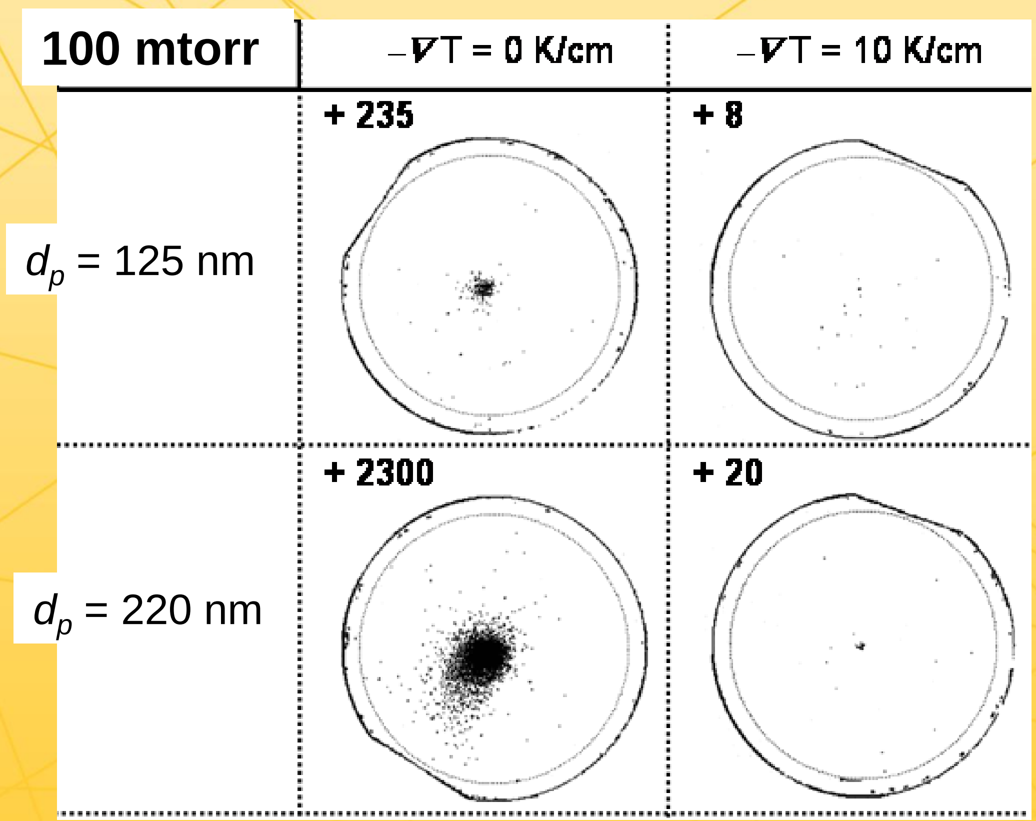
Vacuum chamber





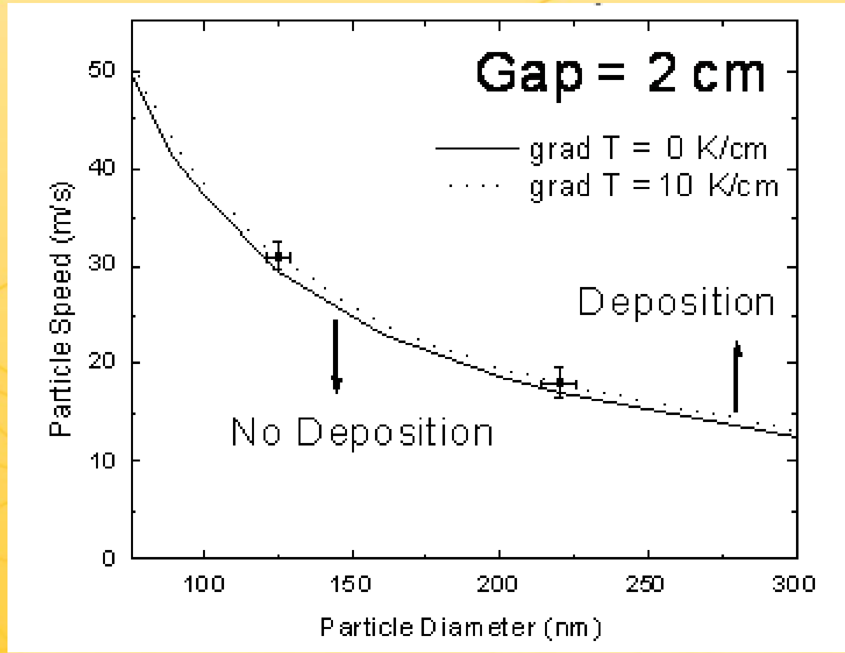


Thermophoresis at 100 mTorr, 2 cm Gap



v_p = 31 m/s for 125 nm

v_p = 18 m/s for 220 nm

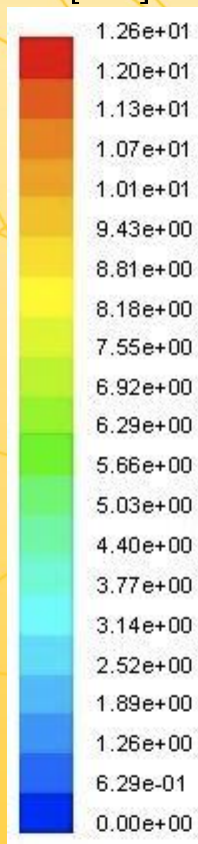


- Thermophoresis improves protection.

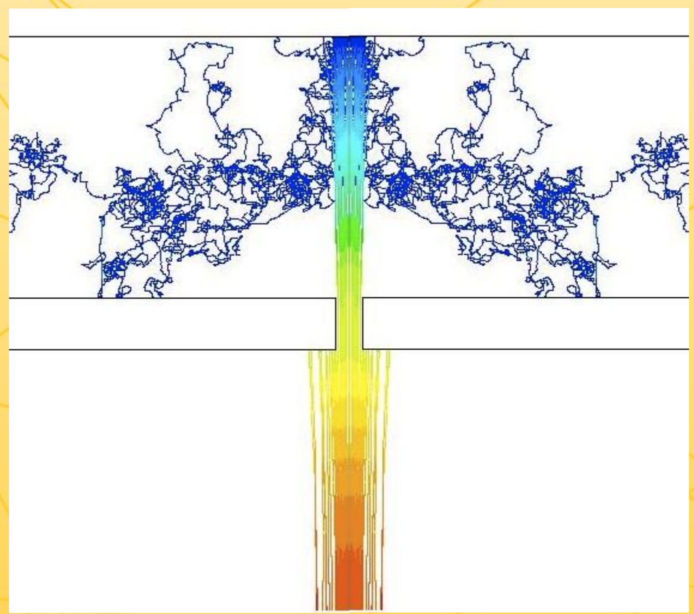
Kim, J.H. et al., *J. Vacuum Sci. Technol. B24(3):1178-1184 (2005)*

Simulations at 50 mTorr
125 nm, 1 cm Gap, v_i = 6.5 m/s

[m/s]



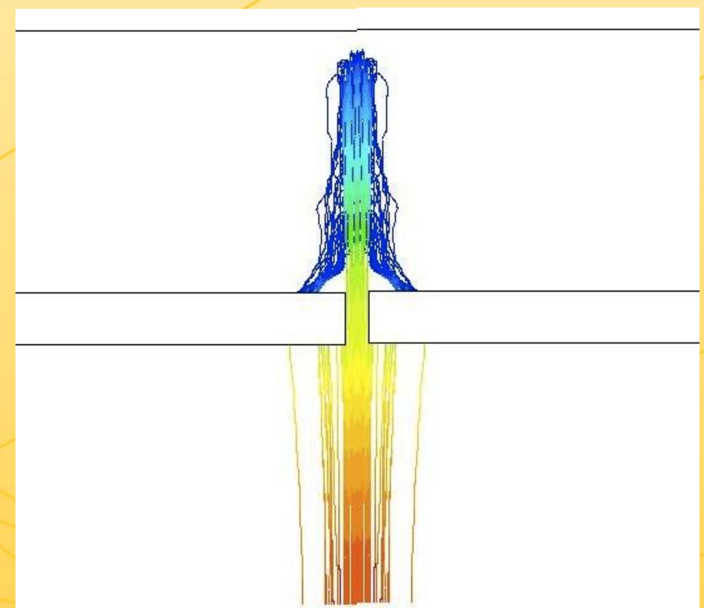
$-\nabla T$ = 0 K/cm



Many particles deposited

(some by diffusion)

$-\nabla T$ = 10 K/cm



No particles deposited

- Thermophoresis overcomes diffusion.

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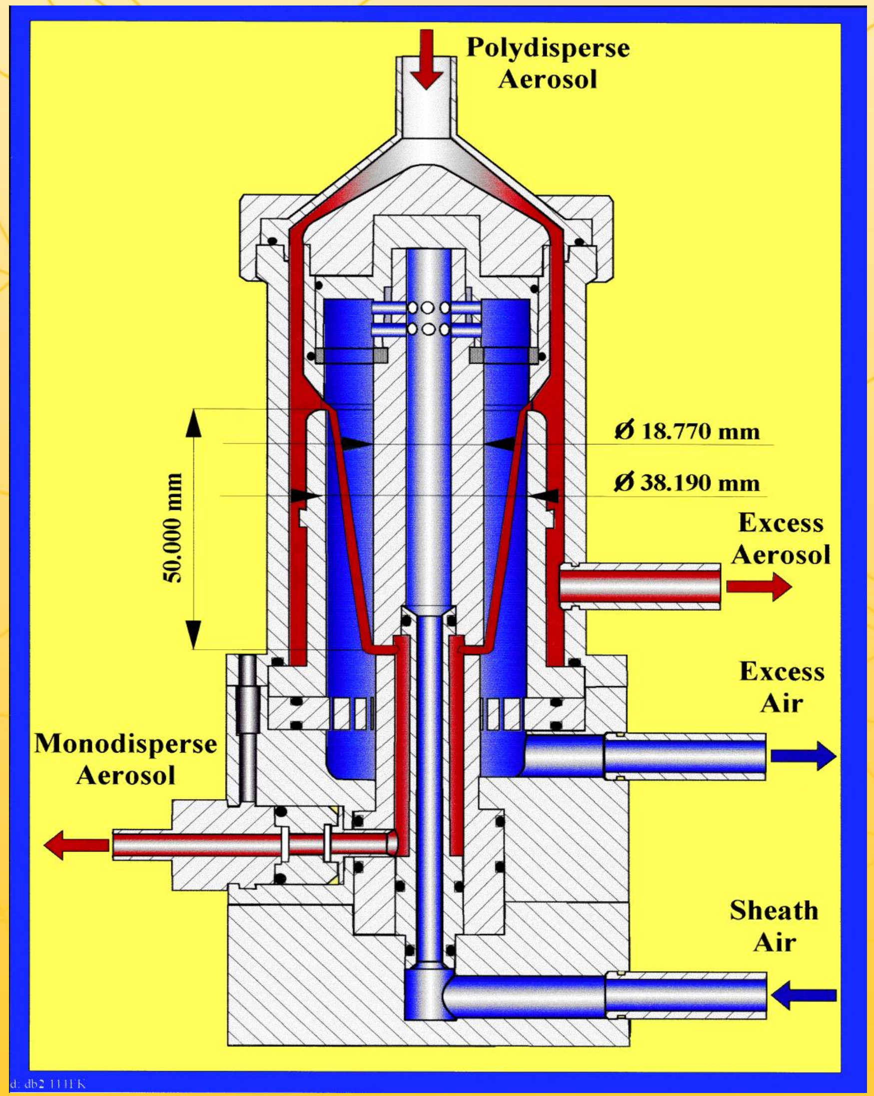
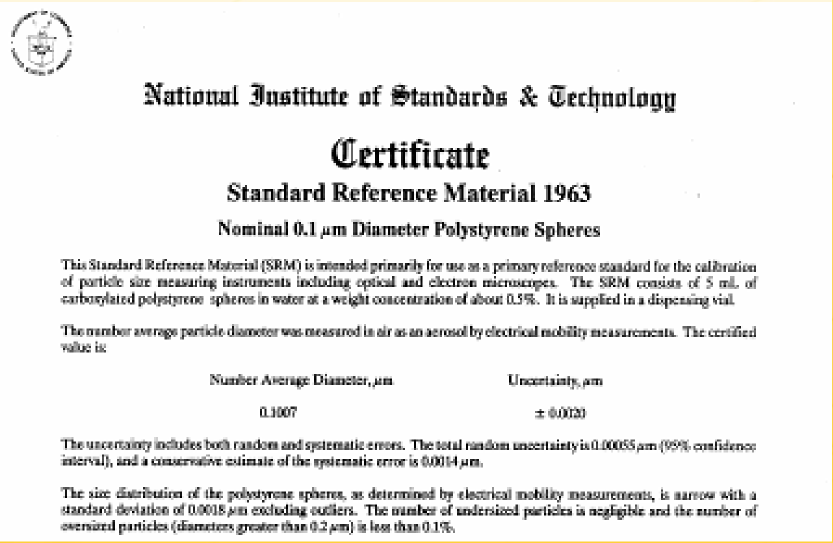
Nanometer Differential Mobility Analyzer (Nano-DMA)





National Institute of Standards & Technology

Certificate

Standard Reference Material 1963

Nominal 0.1 µm Diameter Polystyrene Spheres

This Standard Reference Material (SRM) is intended primarily for use as a primary reference standard for the calibration of particle size measuring instruments including optical and electron microscopes. The SRM consists of 5 mL of carboxylated polystyrene spheres in water at a weight concentration of about 0.5%. It is supplied in a dispensing vial.

The number average particle diameter was measured in air as an aerosol by electrical mobility measurements. The certified value is:

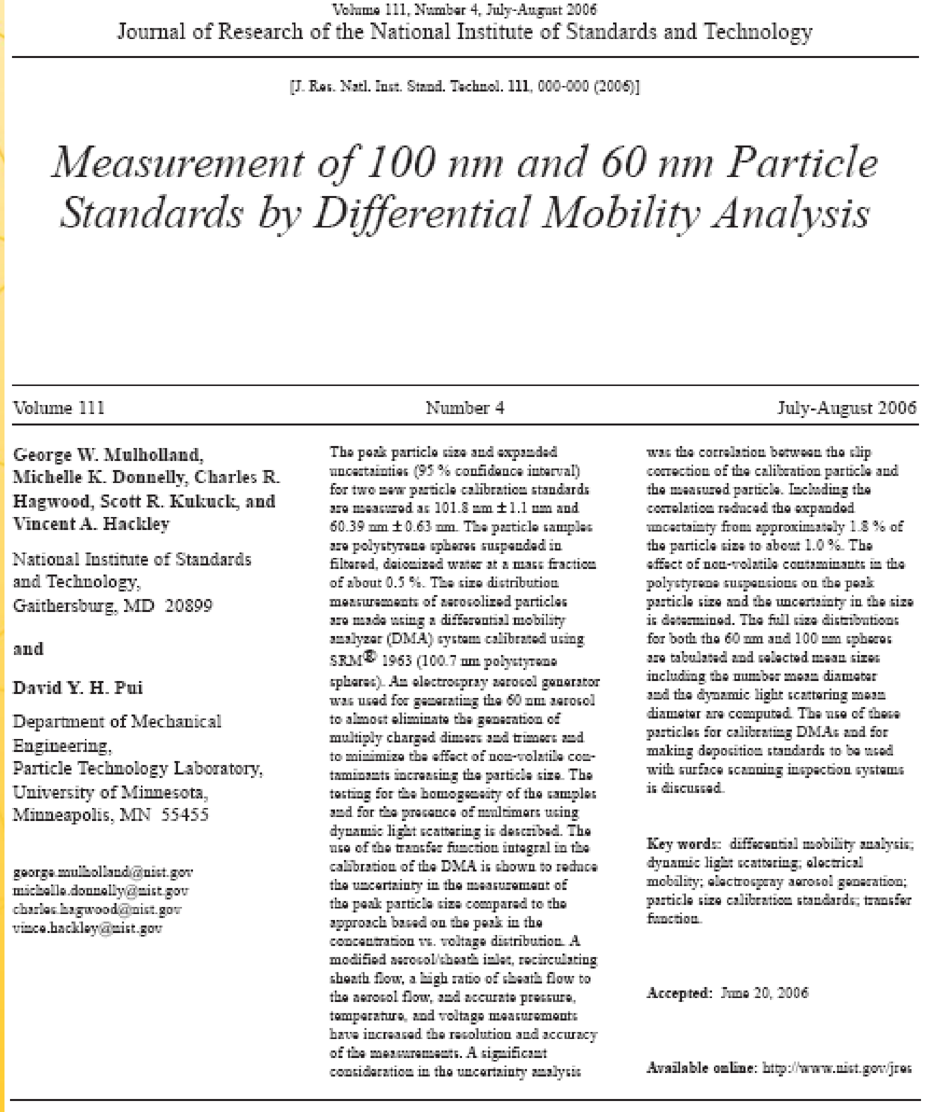
Number Average Diameter, µm	Uncertainty, µm
0.1007	± 0.0020

The uncertainty includes both random and systematic errors. The total random uncertainty is 0.00055 µm (95% confidence interval), and a conservative estimate of the systematic error is 0.0014 µm.

The size distribution of the polystyrene spheres, as determined by electrical mobility measurements, is narrow with a standard deviation of 0.0018 µm excluding outliers. The number of undersized particles is negligible and the number of oversized particles (diameters greater than 0.2 µm) is less than 0.1%.

University of Minnesota

New NIST Nanoparticle Standards:
60 nm and 100 nm SRM



Volume 111, Number 4, July-August 2006
Journal of Research of the National Institute of Standards and Technology

[J. Res. Natl. Inst. Stand. Technol. 111, 000-000 (2006)]

Measurement of 100 nm and 60 nm Particle Standards by Differential Mobility Analysis

Volume 111 | Number 4 | July-August 2006

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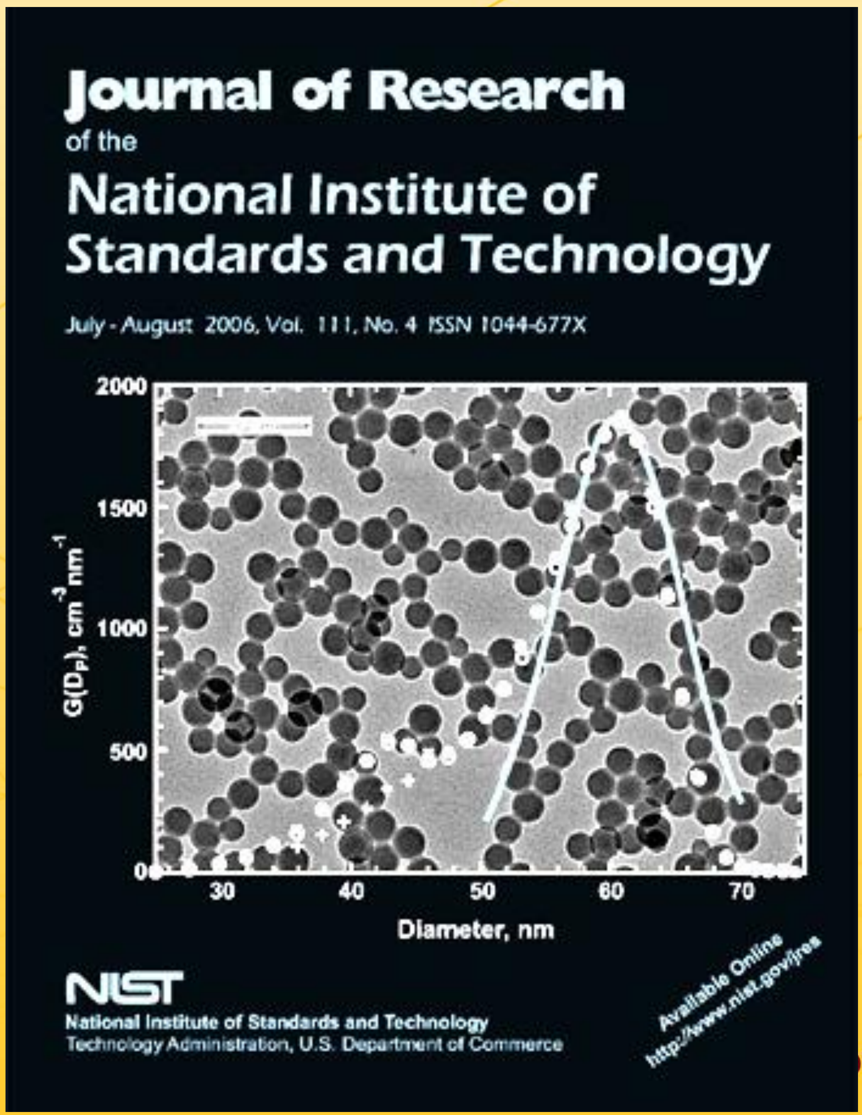
The peak particle size and expanded uncertainties (95 % confidence interval) for two new particle calibration standards are measured as 101.8 nm ± 1.1 nm and 60.39 nm ± 0.63 nm. The particle samples are polystyrene spheres suspended in filtered, deionized water at a mass fraction of about 0.5 %. The size distribution measurements of aerosolized particles are made using a differential mobility analyzer (DMA) system calibrated using SRM® 1963 (100.7 nm polystyrene spheres). An electrospray aerosol generator was used for generating the 60 nm aerosol to almost eliminate the generation of multiply charged dimers and trimers and to minimize the effect of non-volatile contaminants increasing the particle size. The testing for the homogeneity of the samples and for the presence of multimers using dynamic light scattering is described. The use of the transfer function integral in the calibration of the DMA is shown to reduce the uncertainty in the measurement of the peak particle size compared to the approach based on the peak in the concentration vs. voltage distribution. A modified aerosol/sheath inlet, recirculating sheath flow, a high ratio of sheath flow to the aerosol flow, and accurate pressure, temperature, and voltage measurements have increased the resolution and accuracy of the measurements. A significant consideration in the uncertainty analysis was the correlation between the slip correction of the calibration particle and the measured particle. Including the correlation reduced the expanded uncertainty from approximately 1.8 % of the particle size to about 1.0 %. The effect of non-volatile contaminants in the polystyrene suspensions on the peak particle size and the uncertainty in the size is determined. The full size distributions for both the 60 nm and 100 nm spheres are tabulated and selected mean sizes including the number mean diameter and the dynamic light scattering mean diameter are computed. The use of these particles for calibrating DMAs and for making deposition standards to be used with surface scanning inspection systems is discussed.

Key words: differential mobility analysis; dynamic light scattering; electrical mobility; electrospray aerosol generation; particle size calibration standards; transfer function.

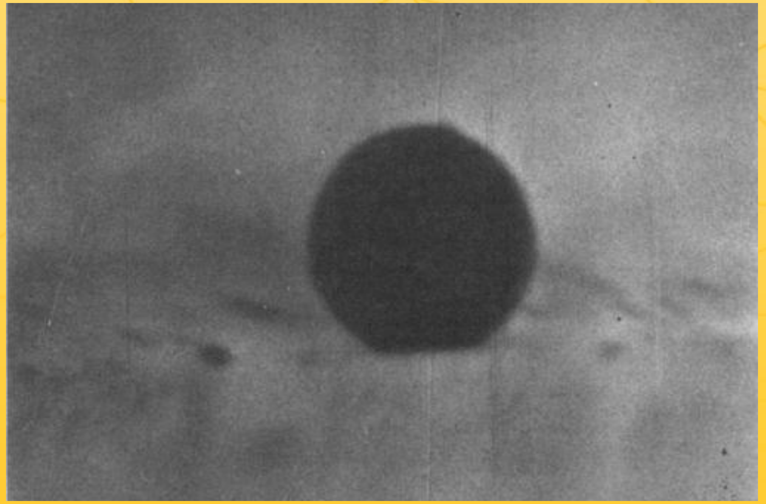
Accepted: June 20, 2006

Available online: http://www.nist.gov/jres



Issues with PSL Particle Standard

- Different light scattering than particles from processes
- Decomposition from exposure to deep ultra-violet (DUV) lights
- Deformation due to adhesion forces



A 1.3 µm PSL sphere after adhering to a chromium surface for 24 hrs. From Dahneke, B. "The influence of flattening on the adhesion of particles," J. Colloid Interface Sci., vol. 40(1), (1972).

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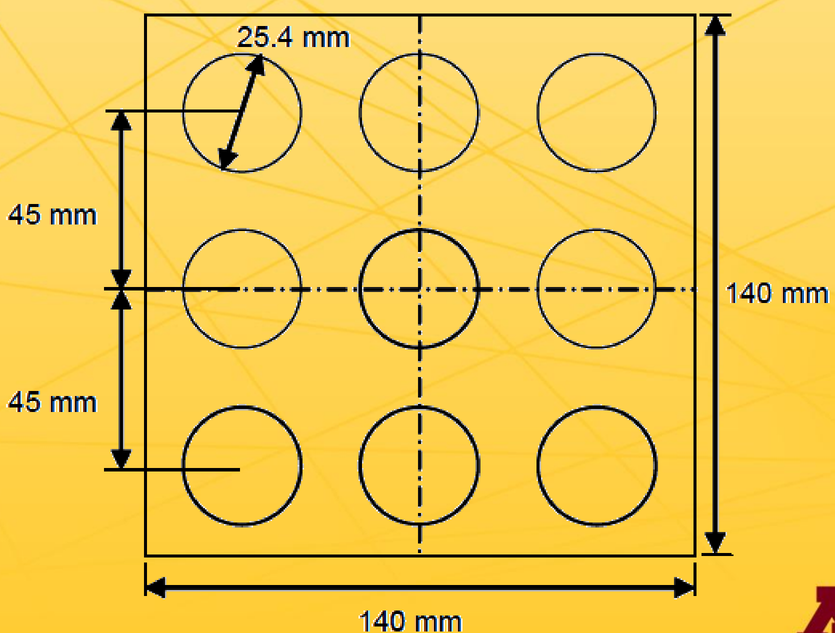
Standard Particle Deposition for Scanner Calibration

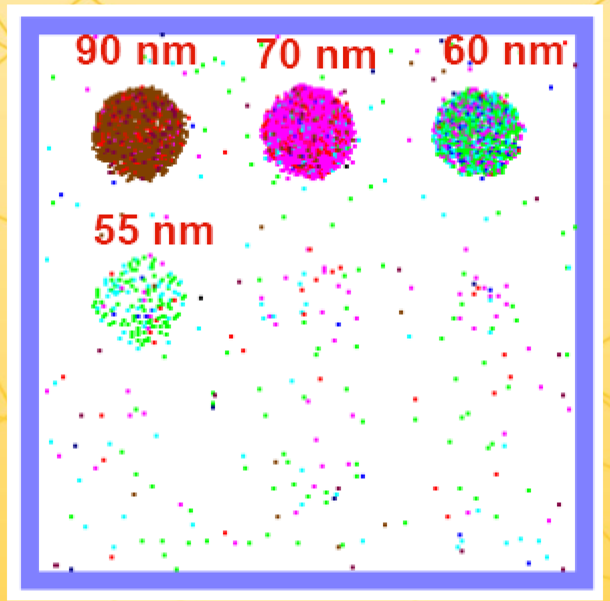
- Calibration of surface inspection tools with particles of different materials
- Development of accurate size standards
- Providing samples for cleaning studies

NIST Traceable Deposition on Photomasks

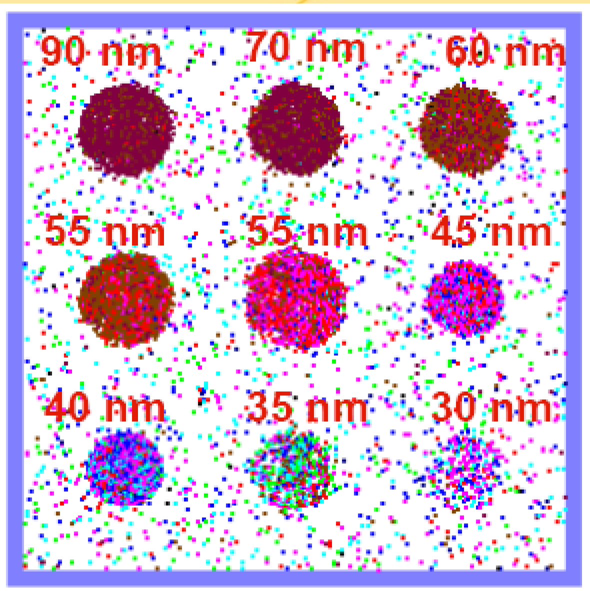
- Particle Size Range: 20 – 900 nm
- Size Uniformity: > 98%
- Particle Counts: 100-2000 particles/spot
- Materials: PSL, SiO_2, TiO_2, Au, Al_2O_3…
- Photomasks: Quartz blank and ML (Ru or CrN Coated)



SiO_2 particles down to 30 nm have been deposited on quartz mask blanks.



M1350 inspection results



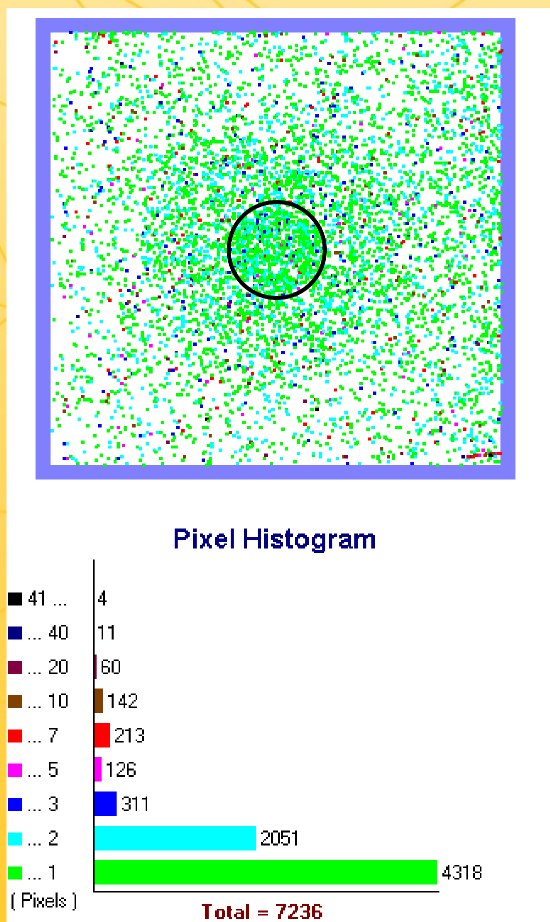
M7360 inspection results

Results in collaboration with Andy Ma and Ted Liang of Intel.

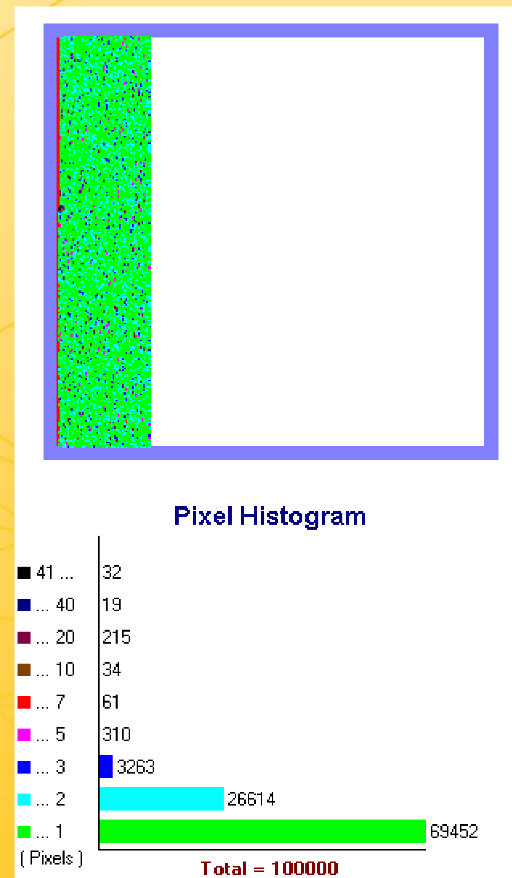
University of Minnesota

Haze Observed under Atmospheric and Vacuum Conditions

50nm SiO_2. Target deposition area: 1inch spot size at the center. Testingtime: 2 min. (Atmospheric Pressure)



100 nm PSL particle. (Main Chamber p = 50 mTorr). Testing time: 1.5 hours



Airborne Molecular Contaminants (AMCs)
Classification of AMCs

Acids

HF H_2SO_4

HCl HNO_3

H_3PO_4 HBr

Bases

AMINE

NH_3

NMP

HMDS

No Classes

H_2O_2 O_3

IPA Acetone

Condensable

DOP DBP DEP

Siloxanes BHT

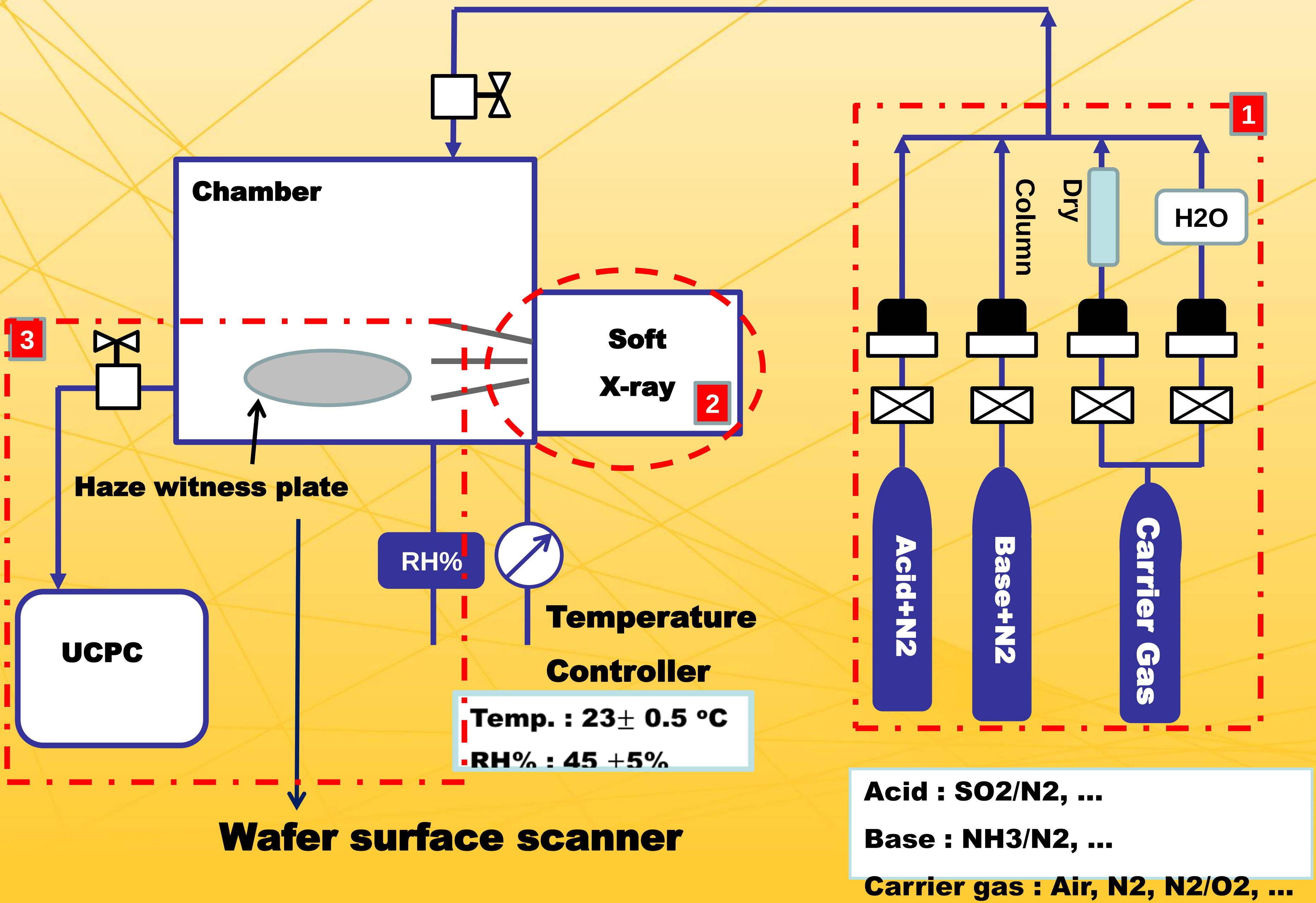
Dopants

B_2H_6 BF_3 AsH_3

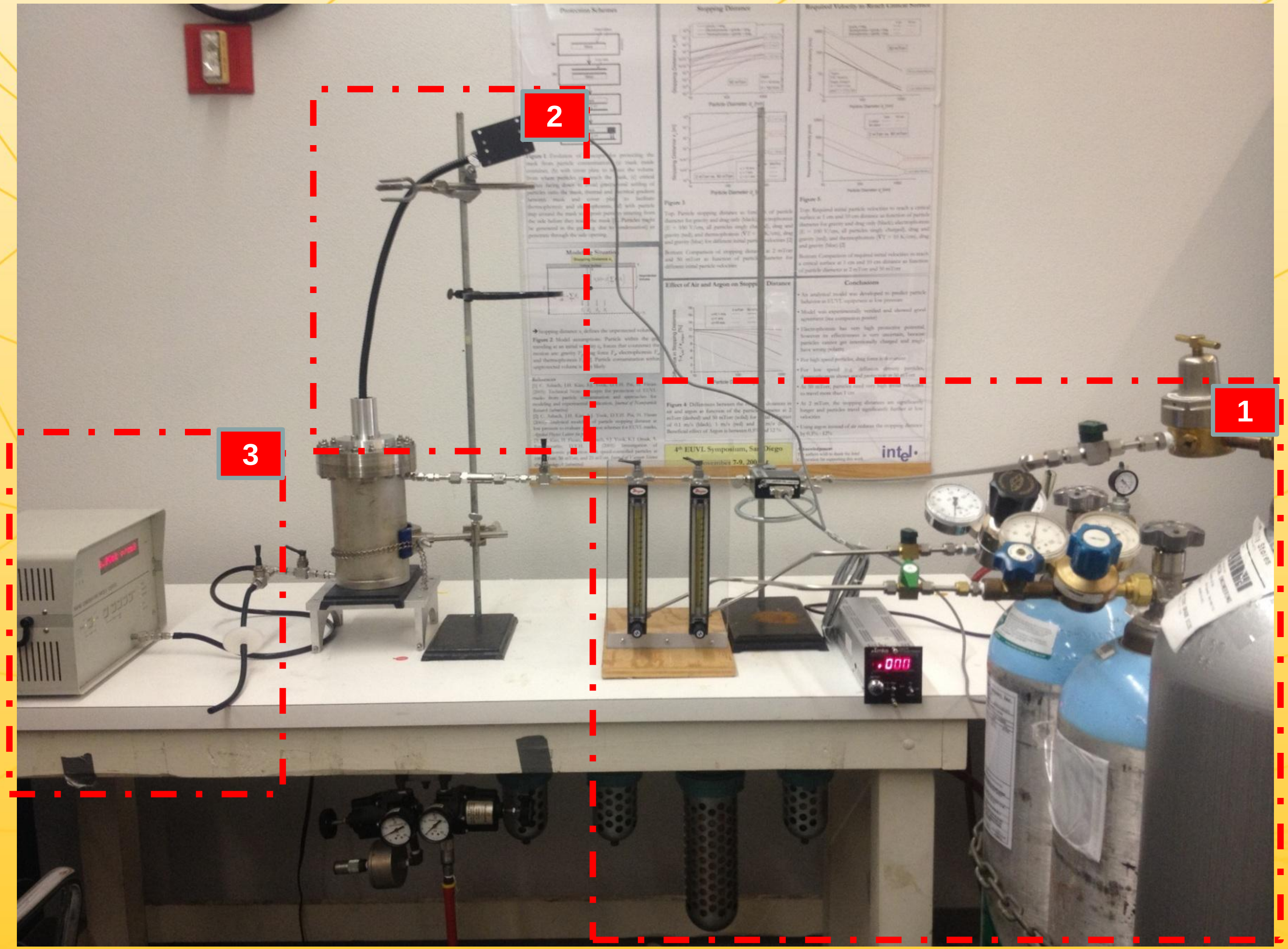
TCEP TEP TPP

SEMI Standard F21-95, 1996

Schematic diagram



Experimental Setup



Particle Generation during Vacuum Pumpdown

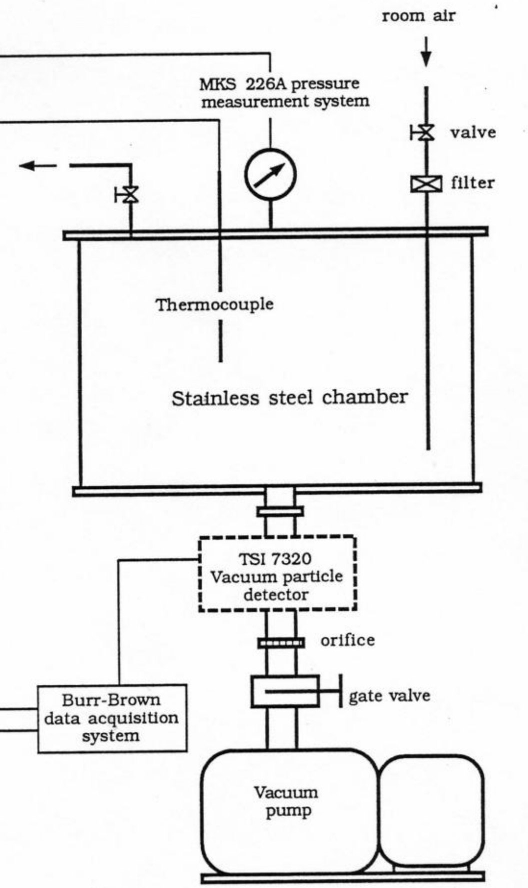


Figure 1 Schematic diagram of vacuum system for particle formation study

Ye, Pui et al., *J. Electrochemical Soc.* 140:1463-1468 (1993).

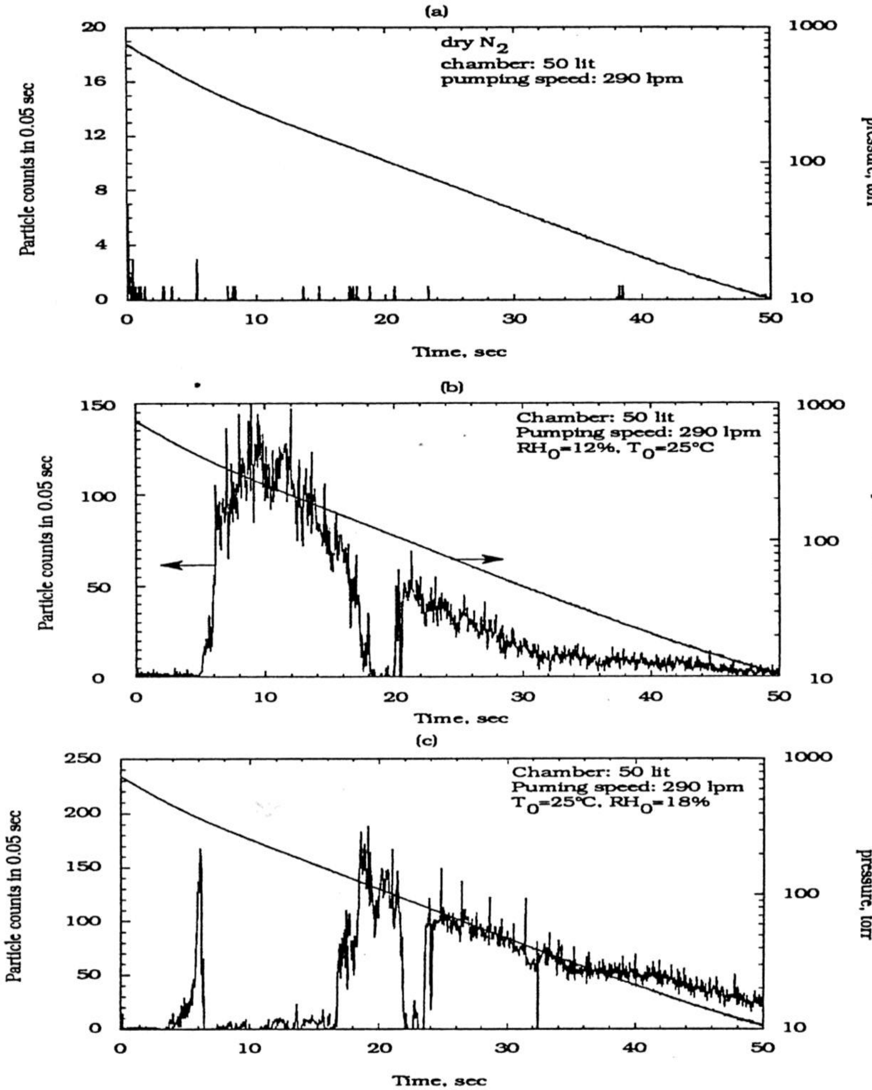


Figure 2. Change of particle counts with time during pump down with various relative humidity

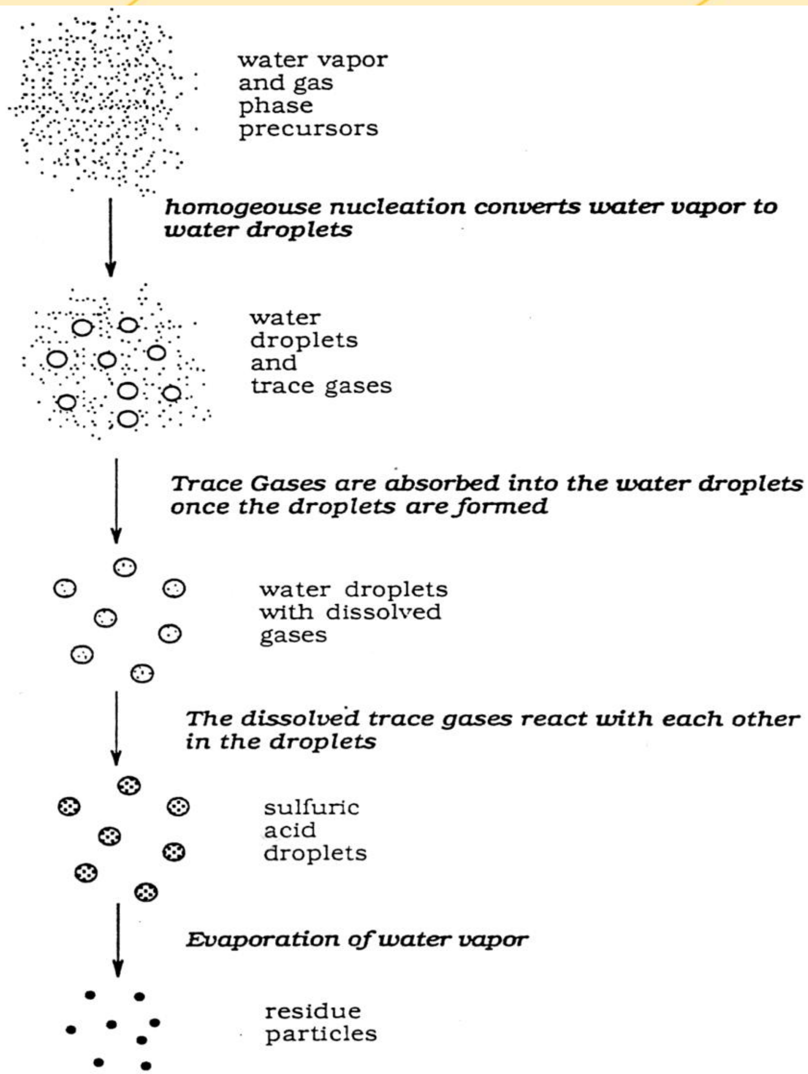
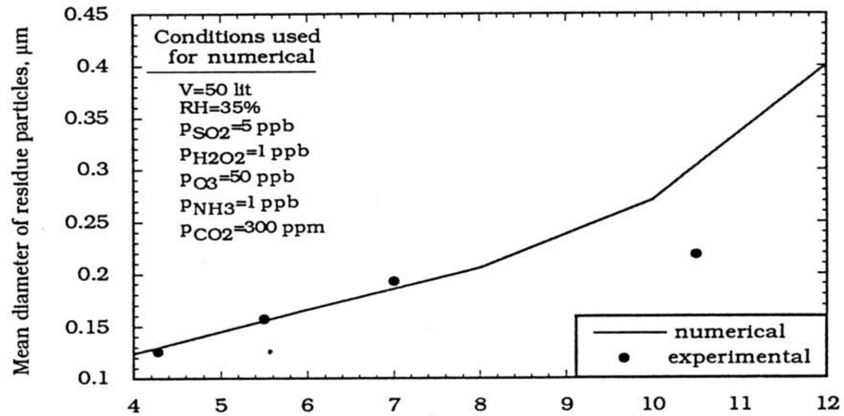
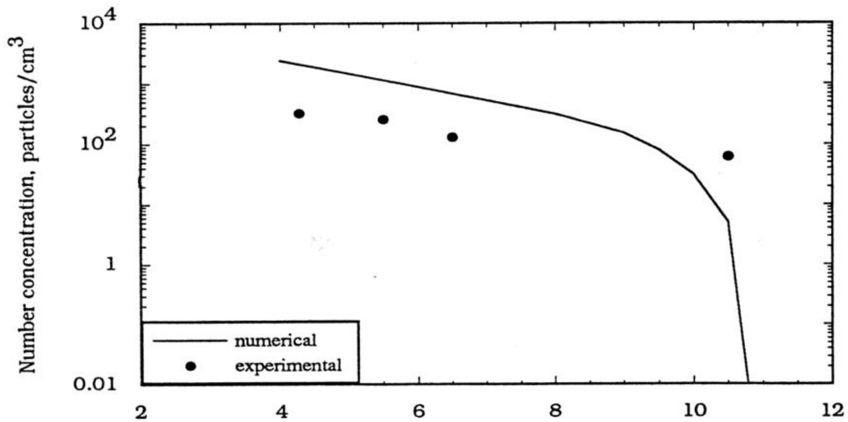


Figure 8. Hypothesis of Residue particle formation process



(a) residue particle size



(b) Number concentration

Figure 9. Comparison of the numerical and experimental results. Effect of pumping speed on residue particle formation

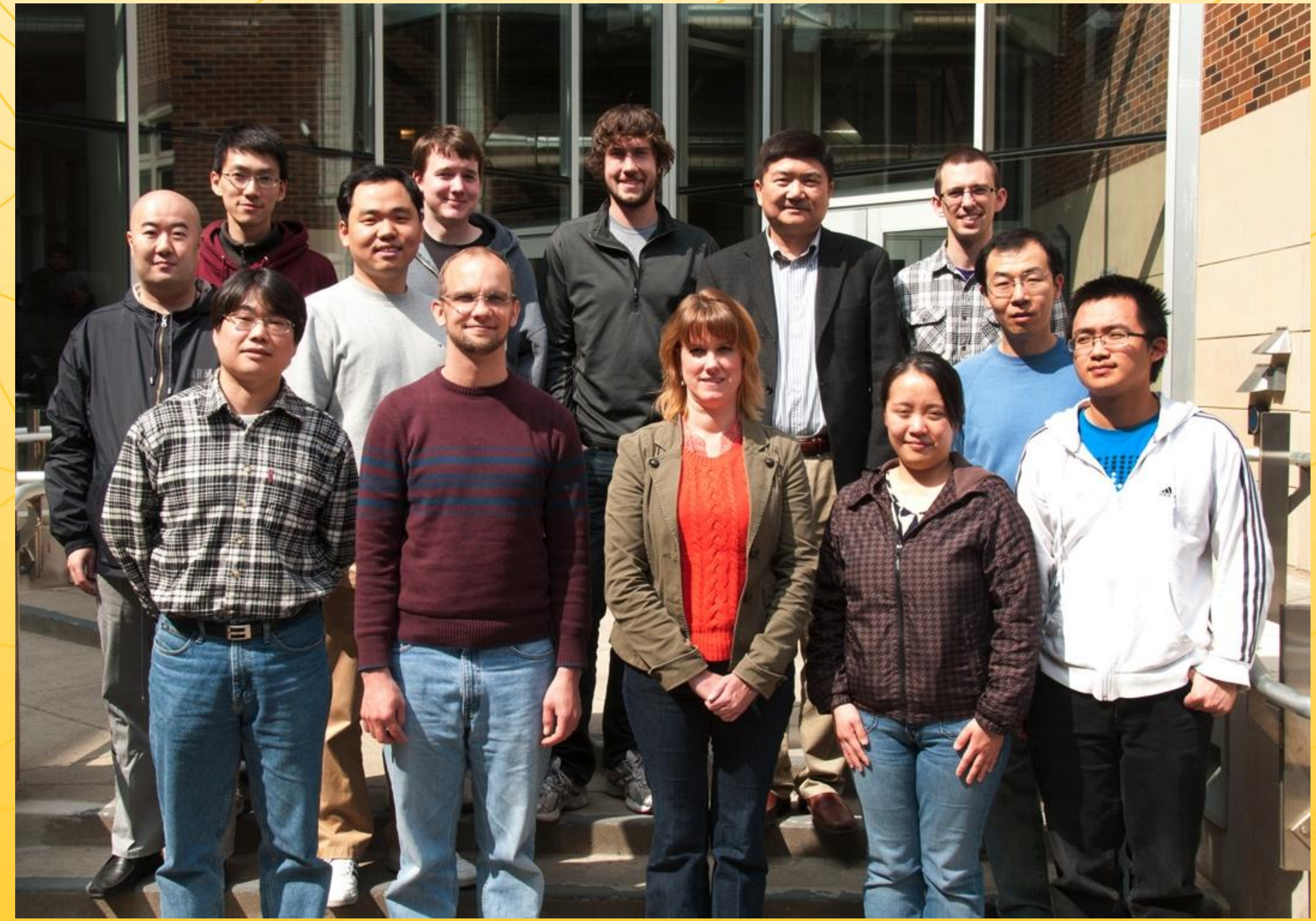
Summary

- Experimental methods and models have been developed to evaluate protection schemes for masks in carrier or vacuum tools.
- New carriers with tapered standoff generates almost no particles during shipping.
- Face-down mounting and cover plate are very effective in protection.
- Thermophoresis is most helpful to protect against particles driven by diffusion.
- Method has been developed to deposit standard nanoparticles for inspection tool calibration.
- Method has been developed to avoid haze formation caused by AMC.

Acknowledgement

- Intel Corporation – Ted Liang, Kevin Orvek, and Peiyang Yan
- Sematech – Andy Ma, Long He
- H. Fissan, U. of Duisburg-Essen
- C. Asbach, T. van der Zwaag, T. Engelke, IUTA, Duisburg
- J.H. Kim, C. Qi, Post-docs
- S.J. Yook, Y. Liu, Ph.D. students

Research Team, 2012



Refereed Journal Papers Published under Intel Support

1. Asbach, C., Kim, J. H., Yook, S. J., Pui, D. Y. H., and Fissan H. (2005) Modeling of protection schemes for critical surfaces under low pressure conditions: comparison of analytical and numerical approach. *Journal of Vacuum Science & Technology B* **23(6)**: 2419-2426.
2. Asbach, C., Kim, J. H., Yook, S. J., Pui, D. Y. H., and Fissan H. (2005) Analytical modeling of particle stopping distance at low pressure to evaluate protection schemes for EUVL masks. *Applied Physics Letters* **87**: 234111.
3. Asbach, C., Fissan, H., Kim, J. H., Yook, S. J., and Pui, D. Y. H. (2006) Technical Note: Concepts for protection of EUVL masks from particle contamination and approaches for modeling and experimental verification. *J. Nanoparticle Research*, **8**, 705 – 708.
4. Kim, J. H., Asbach, C., Yook, S. J., Fissan H., Orvek, K., Ramamoorthy, A., Yan, P. Y., and Pui, D. Y. H. (2005) Protection schemes for critical surfaces in vacuum environment. *J. Vacuum Science & Technology A* **23(5)**:1319-1324.
5. Kim, J. H., Fissan, H., Asbach, C., Yook, S. J., and Pui, D. Y. H. (2006) Speed controlled particle injection under vacuum conditions. *J. Vacuum Science & Technology A*, **24(2):** 229-234**.**
6. Kim, J. H., Fissan, H., Asbach, C., Yook, S. J., Orvek, K., and Pui, D. Y. H. (2006) Investigation of thermophoretic protection with speed-controlled particles at 100, 50, and 25 mTorr. *J. Vacuum Science & Technology B*, **24(3):** 1178-1184.
7. Kim, J. H., Fissan, H., Asbach, C., Yook, S. J., Wang, J., Pui, D. Y. H., and Orvek, K. J. (2006) Effect of reverse flow by differential pressure on the protection of critical surfaces against particle contamination. Journal of Vacuum Science & Technology B **24(4):**1844-1849.
8. Asbach, C., Fissan, H., Kim, J. H., Yook, S. J., and Pui, D. Y. H. (2007) A Simple theoretical approach to estimate the effect of gravity and thermophoresis on the diffusional nanoparticle contamination under low pressure conditions, *J. Vac. Sci. & Technol. B*, **25(1):** 47 – 53.
9. Yook, S. J., H. Fissan, C. Asbach, J. H. Kim, J. Wang, P. Y. Yan, and D. Y. H. Pui, (2007) Evaluation of protection schemes for extreme ultraviolet lithography (EUVL) masks against top–down aerosol flow, *J. Aerosol Sci.* **38**, 211 – 227, Feb. 2007.

10. Engelke, T., T. van der Zwaag, C. Asbach, H. Fissan, J. H. Kim, S. J. Yook, and D. Y. H. Pui, (2007) Numerical Evaluation of Protection Schemes for EUVL Masks in Carrier Systems Against Horizontal Aerosol Flow, *J. Electrochem. Soc.* **154**, H170–H176.
11. Yook, S. J., Fissan, H., Asbach, C., Kim, J. H., van der Zwaag, T., Engelke, T., Yan, P. Y., and Pui, D. Y. H. (2007) Experimental investigations on protection schemes for extreme ultraviolet lithography (EUVL) mask carrier systems against horizontal aerosol flow, *IEEE Transactions on Semiconductor Manufacturing* **20(2):**176-186.
12. Yook, S. J., Fissan, H., Kim, J. H., van der Zwaag, T., Engelke, T., Asbach, C., Eschbach, F., Wang, J., and Pui, D. Y. H, (2008) Controlled Deposition of SiO2 Nanoparticles of NIST-Traceable Particle Sizes for Mask Surface Inspection System Characterization, *IEEE Trans. Semiconduct. Manuf.* **21(2):**238-243.
13. Yook, S.J., H. Fissan, C. Asbach, J. H. Kim, D. D. Dutcher, P. Y. Yan, and D. Y. H. Pui, (2007) Experimental investigations on particle contamination of masks without protective pellicles during vibration or shipping of mask carriers, *IEEE Trans. Semicond. Manuf*. **20(4):**578-584.
14. Yook, S. J. H. Fissan, T. Engelke, C. Asbach, T. van der Zwaag, J. H. Kim, J. Wang, and D. Y. H. Pui (2008) Methods to deposit nanoparticles of NIST-traceable sizes on a mask or a wafer surface for characterizing surface inspection tools, *J. Aerosol Sci.* (in press)
15. Asbach, C., Stahlmecke, B., Fissan, H., Kuhlbusch, T., Wang, J. and Pui, D. Y.H. (2008) Analytical-statistical model to approximate diffusional nanoparticle deposition on inverted surfaces at low pressure, *Applied Physics Letters* **92(6):**064107.
16. Wang, J., Pui, D. Y.H., Qi, C., Yook, S.J., Fissan, H., Ultanir, E. and Liang, T. (2008) Controlled Deposition of NIST-traceble Nanoparticles as Additional Size Standards for Photomask Applications, *Proc. of SPIE* Vol. 6922:69220G.

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